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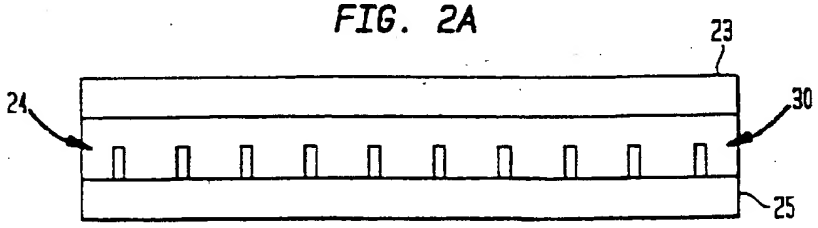
(54) Electrophoretic display and method of making the same

(57) A configuration for an electrophoretic display device is described that is effective in substantially preventing agglomeration of pigment particles. A suspension medium (in 30) is contained between first (23) and second (25) electrodes to define an electrophoretic display cell; a plurality of pigment particles are dispersed in the suspension medium and a plurality of mechanical members (24) project therein. The members advantageously are sized sufficiently small such that a plurality of members can exist within a minimally visible region of the cell. The mechanical members may be fabricated separately from the remaining parts of the display, allowing for flexibility in the fabrication materials and processing conditions.

FIG. 2A



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[0008] The microcapsules are closed microscopic vessels fabricated using coacervation, interfacial polymerization, or in-situ polymerization. The microcapsules do not entirely prevent agglomeration but they confine it within single capsules, which typically are too small to be seen by eye. Although this technique minimizes the adverse effects of agglomeration, it has disadvantages. For instance, fabrication of the microcapsules involves polymerization schemes carried out in the presence of the colored liquids and charged particles. Precise control must be exercised over the processing conditions such as the temperature, pH, and starting material concentrations, and it is difficult to control the size or uniformity of the microcapsules. These polymerization schemes place limits on the materials that may be used for the device and require additional fabrication steps. The starting materials, any intermediates, and of course, the end products need to be chemically compatible with the rest of the device, e.g., the materials used for the pigment particles and suspension medium, as the fabrication is performed in-situ.

[0009] Another approach for addressing agglomeration involves placing a charge on the pigment particles. For example, U.S. Pat. No. 5,403,518, "*Formulations for Improved Electrophoretic Display Suspensions and Related Methods*," issued April 4, 1995 to Schubert and assigned to Copytele Inc., uses a charge control agent adsorbed on the pigment particles for preventing agglomeration. U.S. Pat. No. 4,680,103, issued July 14, 1987 to Beilen, "*Positive Particles in Electrophoretic Display Device Composition*," describes attaching an organosilane to each of the particles where the organosilane includes a positively charged ionic functional moiety covalently bonded therein.

[0010] Other approaches involve using pulsed and DC voltages to periodically redistribute the particles or use of "electrostatic compartments" to restrict particle movement to a defined region. These approaches, if effective, require significant increases in the complexity of the electrodes and drive circuitry. S. Beilin *et al.*, "*2000 Character Electrophoretic Display*," SOCIETY OF INFORMATION DISPLAY 86 Digest (1986), at p. 136. However, these approaches have never been demonstrated to be sufficiently effective for commercial devices with long lifetime.

[0011] As may be appreciated, techniques for improving the performance and lifetimes of EPDs are desired. The feasibility of commercializing EPDs depends on the development of effective approaches for eliminating agglomeration.

Summary Of The Invention

[0012] The applicants have discovered a configuration for an electrophoretic display device that is effective in substantially preventing agglomeration of the pigment particles. With this configuration, a suspension medium is contained between first and second electrodes to define a cell; a plurality of pigment particles are dispersed in the suspension medium; and a plurality of mechanical members project in the suspension medium. The members advantageously are sized sufficiently small that a plurality of members can exist within a minimally visible region of the cell, and they are configured (e.g., depending on size and materials), to have no adverse impact on the appearance of the display. The mechanical members may be fabricated separately from the remaining parts of the display, allowing for flexibility in the fabrication materials and processing conditions.

Brief Description Of The Drawings

[0013] For a better understanding of the invention, an exemplary embodiment is described below, considered together with the accompanying drawings, in which:

FIG. 1 is a schematic illustration of a prior art electrophoretic display device;

FIGS. 2A-2D schematically illustrate exemplary alternative embodiments of the electrophoretic display device;

FIGS. 3A-3D schematically illustrate preliminary steps of a method for making the electrophoretic display device;

FIGS. 4A-4B illustrate exemplary processing steps subsequent to the steps of FIGS. 3A-3D; and

FIGS. 5A-5D illustrate alternative exemplary processing steps subsequent to the steps of FIGS. 3A-3D.

[0014] It is to be understood that these drawings are for the purposes of illustrating the concepts of the invention and are not to scale.

Detailed Description Of The Invention

[0015] With this invention, small-scale mechanical members are used to prevent non-uniformities among the charged particles, e.g., from agglomeration, These members are constructed to break apart any agglomeration as the particles travel from one side of the cell to the other. The members are not necessarily electrically active components, but their shape, distribution, and placement within the cell reverse the effects of agglomeration during operation of the display. In addition to reversing agglomeration, these mechanical members can act to frustrate segregation before large agglomerates can form. In other words, the mechanical members function to reduce agglomeration in at least two ways, i.e., they break up agglomeration that already has

pany (Dow) under the tradename SYLGARD 184.™ The prepolymer may then be cured. When PDMS is used, a suitable curing step involves heating to about 65°C for about two hours. The solid PDMS is then removed from the wafer to provide the flexible mold 33. Advantageously, the mold is fabricated with a transparent material so that the material forming the mechanical members can be cured by applying UV light through the mold, as further described below.

[0021] In FIG. 3A, a first step of fabricating the mechanical members with the mold is shown. An ultrathin liquid film 32 is spin-cast on a substrate 25'. By ultrathin is meant that the film has a thickness of about 20-40 μm, more preferably about 30 μm. The substrate 25' may be flat or structured. It may serve as the bottom electrode of the electrophoretic display device. The liquid advantageously may comprise a photocurable polymer such as an epoxy. A suitable epoxy is available from Dow under the tradename DEN 431. To assist in spin casting a thin layer on the substrate, the epoxy may be diluted with solvent. For example, epoxy novolac may be mixed with a small amount of an acrylate photosensitizer (~3% by weight), and diluted at a ratio of about 2:1 by weight with propylene glycol monomethyl ether acetate (PGMEA) (2 parts epoxy to 1 part PGMEA). The resulting liquid may be spin cast onto the silicon wafer substrate 25', and speeds of about 1000 rpm for about 40 seconds produce an ultrathin liquid film. The PGMEA is sufficiently volatile that it evaporates during spinning.

[0022] Referring to FIG. 3B, the mold 33 is then brought into contact with the liquid film 32. The flexibility of the mold may be exploited to avoid the formation of air bubbles. For example, the surface of the mold may be gradually placed over the liquid film 32, e.g., as by first placing only the center of the mold in contact with the liquid film and then gradually allowing the surface of the mold to contact the film out to its edges, or by first placing one edge of the mold in contact with the film and then gradually proceeding to deposit the mold across the surface of the wafer.

[0023] Referring to FIG. 3C, with the mold 33 in place, the liquid film is solidified. This may be achieved by exposing the film 32 to ultraviolet light. When a mold having a thickness of about 1 cm is placed over a film having a thickness of about 20 μm, a high power mercury lamp applied at about 4000 $\mu W/cm^2$ for about 45 minutes works to cure the film. The mold then may be removed to provide the structure of FIG. 3D. A flexible mold is advantageous again in the removal step in that it may be removed by peeling from the cured polymer film 32.

[0024] Once the molded film on the substrate is provided, as in FIG. 3D, various alternative approaches may be used to fabricate the electrophoretic display device. For example, a top electrode 23 may be secured to the patterned film as in FIG. 4A. The contours 24' of the molded film define the mechanical members, and between the members cells 28' may be formed within the device. The contours 24' need not be in contact with the top electrode 23, so that liquid may flow between the cells 28', although it is also possible for the cells 28' to encapsulate the particles therein. As can be seen, there is flexibility in the fabrication of the members, and precise controls over their alignment are not required. Alternatively, two structures having the molded film and substrate may be aligned facing each other, as in FIG. 4B. In any case, the gap 30 between the electrodes may be filled by capillary action with a liquid suspension medium suitable for an electrophoretic display, e.g., containing pigment particles, and then the edges of the display may be sealed to prevent leakage of the liquid and form the sealed chamber 30. Materials suitable for the various parts of the device including the suspension medium, pigment particles, and sealed edges are known in the field and described in the various references, identified above, and in PCT patent application Serial No. PCt/US98/17734 to E-Ink Corp., titled "*Electrophoretic Displays and Materials*," published March 4, 1999, incorporated herein by reference.

[0025] In FIGS. 5A-5D, alternative processing steps subsequent to the formation of the molded film/substrate structure of FIG. 3D are shown. In FIGS. 5A-5B, the thin regions of the molded film are etched away to provide separate mechanical members 24. In FIG. 5C, the cavities between the members may be filled with suspension medium, a top electrode 23 may be bonded thereon, a suspension of charged particles may be injected between the electrodes, and the gap sealed to prevent the leakage of fluid. Alternatively, where the substrate 25' used to fabricate the molded film 32 and etched members 24 (FIG. 5B), is made of a material other than that desired for the bottom electrode, the etched film may be removed from the substrate 25', and transferred to an electrode/substrate 25, as in FIG. 5D. The etched film 24 on the bottom electrode/substrate 25 (FIG. 5D), may be coated with a suspension medium, and then a top electrode 23 added and the edges sealed to complete the electrophoretic display device.

[0026] It is understood that the embodiments described herein are merely exemplary and that a person skilled in the art may make variations and modifications without departing from the spirit and scope of the invention. All such variations and modifications are intended to be included within the scope of the appended claims.

Claims

1. An electrophoretic display device comprising:

   first and second electrodes;

   a suspension medium contained between the first and second electrodes to define a display cell;

FIG. 1

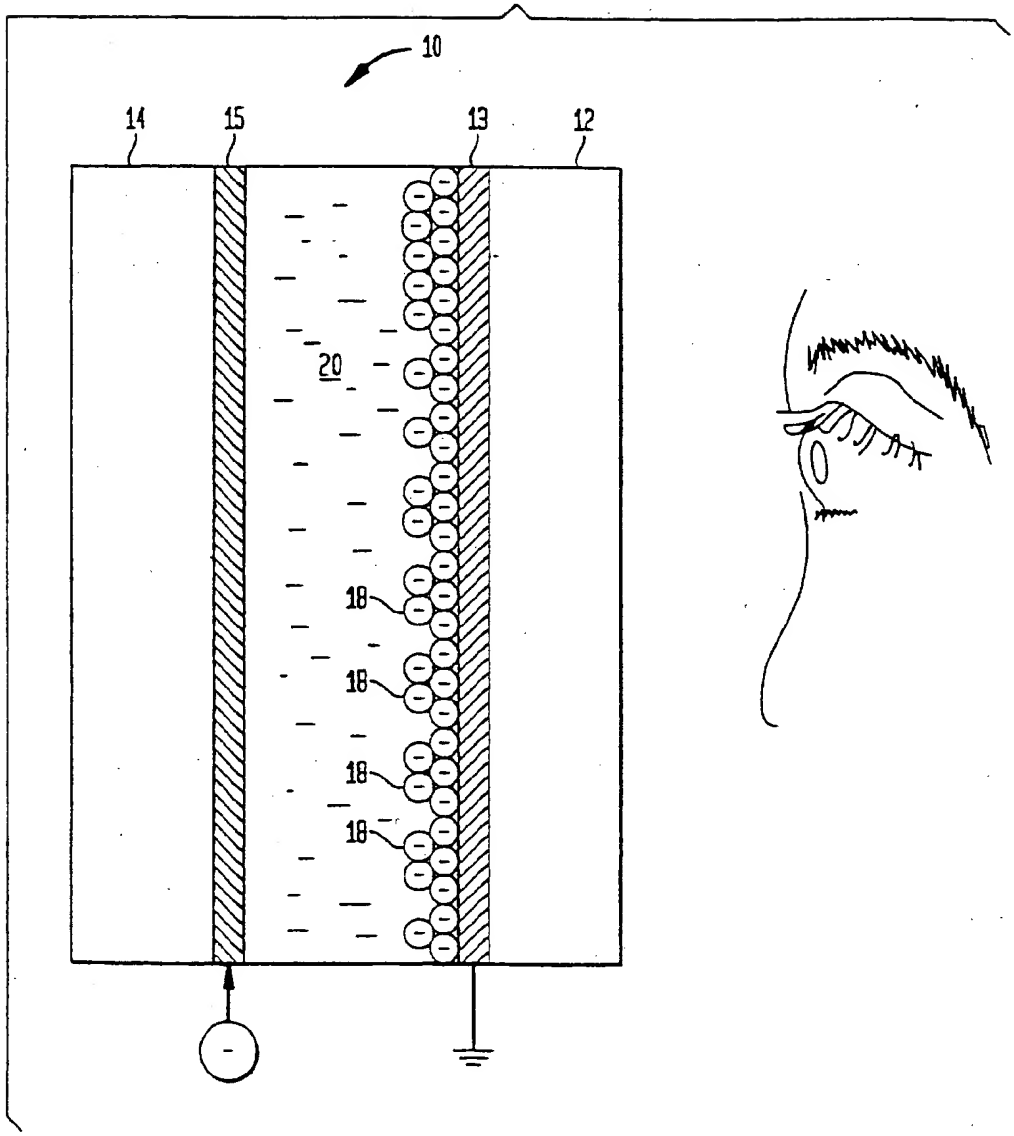

FIG. 3A

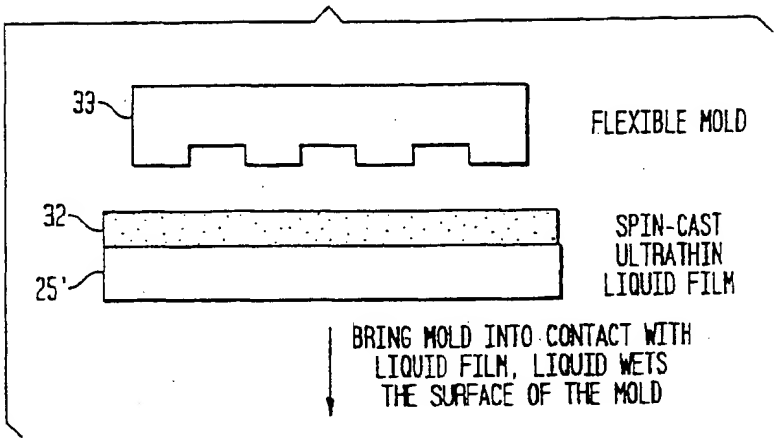

FIG. 3B

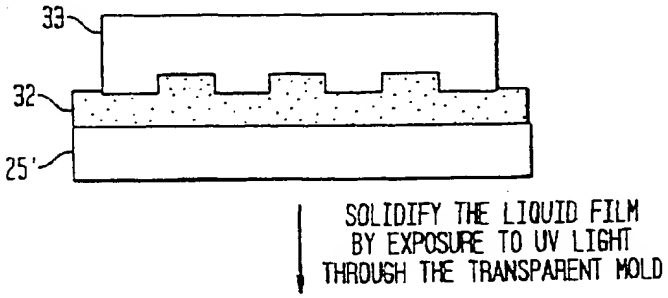

FIG. 3C

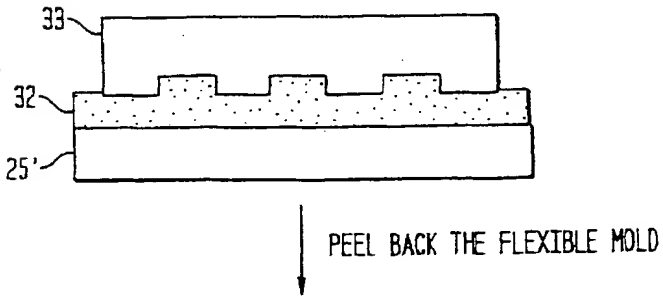

FIG. 3D

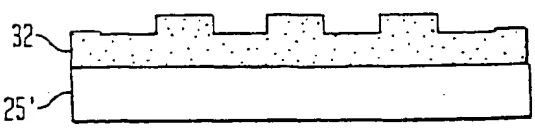

FIG. 5A

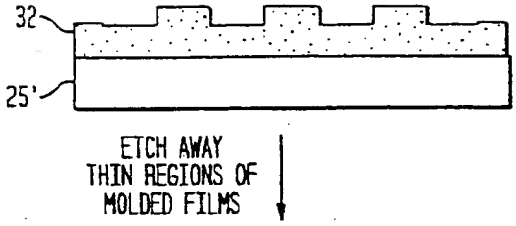

FIG. 5B

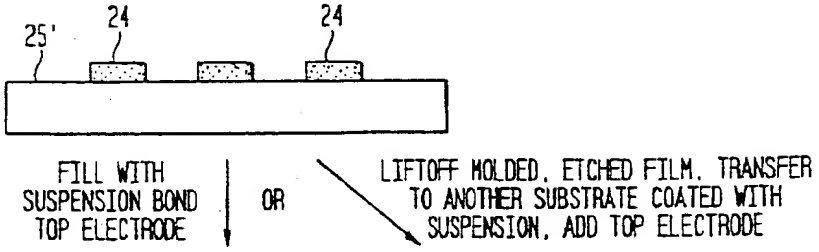

FIG. 5C

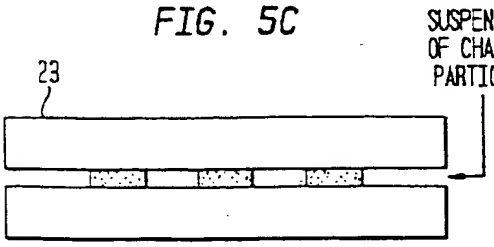

FIG. 5D

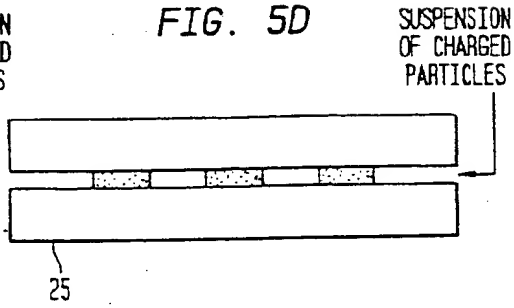

FIG. 1

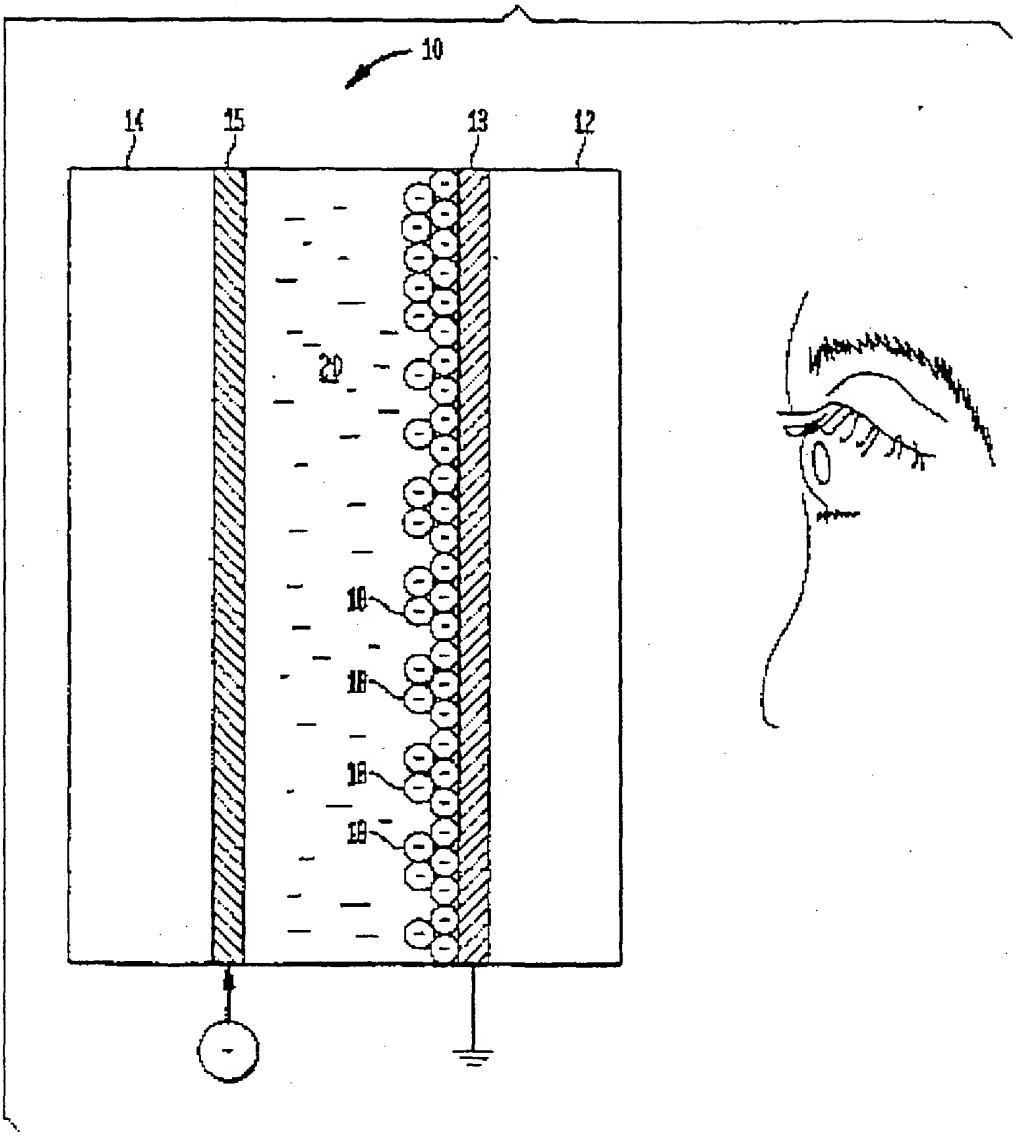

FIG. 3A

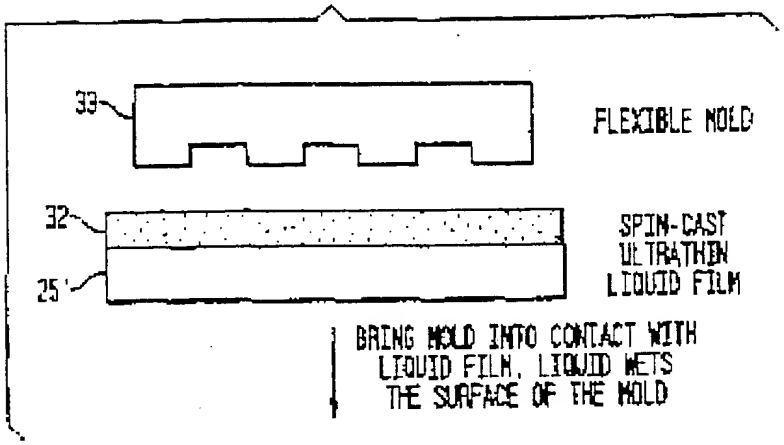

FIG. 3B

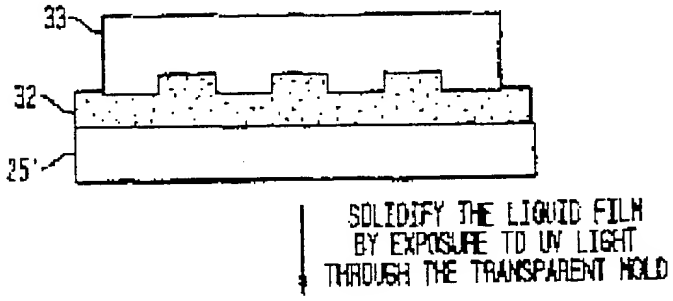

FIG. 3C

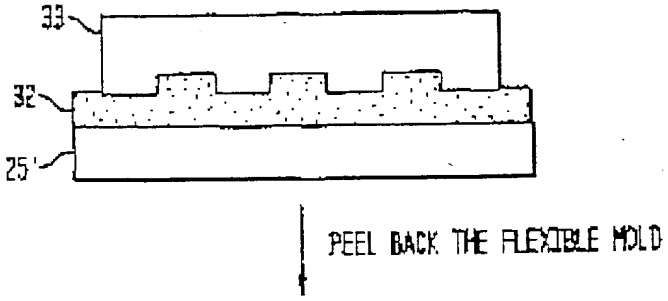

FIG. 3D

FIG. 5A

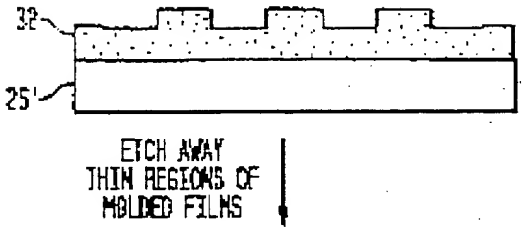

FIG. 5B

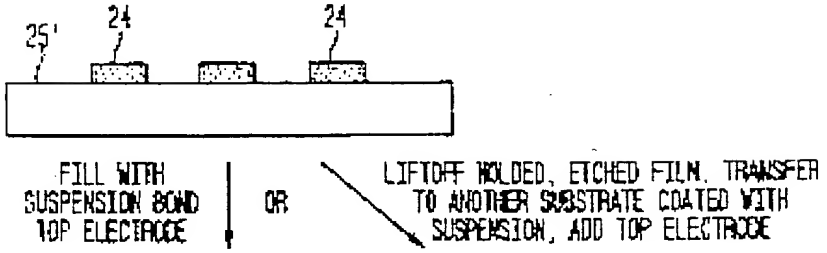

FIG. 5C

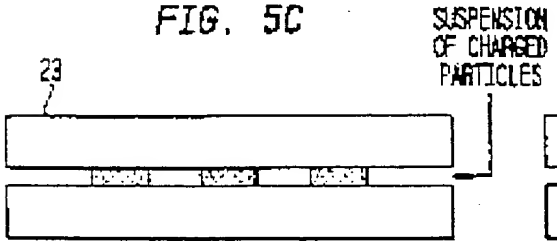

FIG. 5D

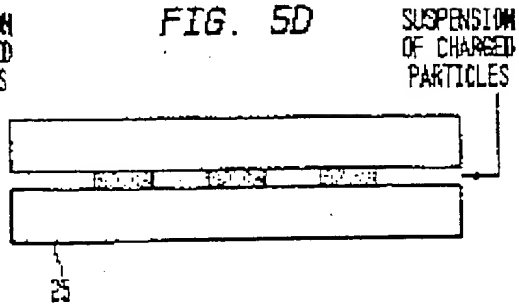

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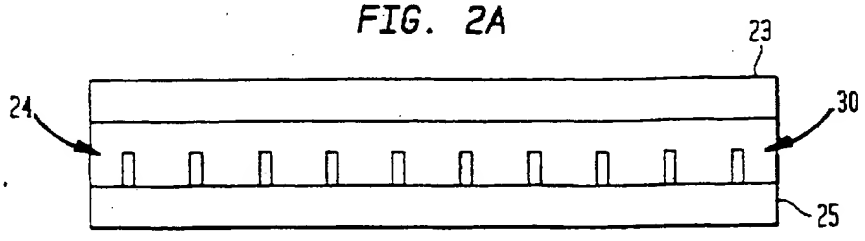
FIG. 2A



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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 30 8087

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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23-05-2001

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JP 59171930 A	28-09-1984	NONE	

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